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METHODOLOGY FOR MEASUREMENT OF FOG OIL SMOKE PENETRATION INTO A RED-COCKADED WOODPECKER NEST CAVITY

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13. ABSTRACT *(Maximum 200 words)*
The Red-Cockaded Woodpecker (RCW) is a threatened and endangered species of bird found predominately in the Southeast United States. Of particular interest to the U.S. Army are the colonies that reside on the U.S. Army installations throughout the Southeast. For years, the U.S. Army has been using battlefield smokes for training and development. The possible impact smoke usage may have on the environment and enactment of new clean air legislation nationwide has begun to limit open air smoke testing and training at numerous Army and Department of Defense locations. While smoke plume modeling and measurement studies, and environmental fate and effects work has been done to assess the impact of many smoke materials, data is limited concerning the possible protection that a tree trunk nest cavity may afford its inhabitant. This project represents the first look at the potential for Fog Oil aerosol to penetrate into a tree trunk nest cavity. Test data indicate that 60% of the challenge Fog Oil smoke may penetrate man-made model nest cavities. Testing using harvested RCW made nest cavities indicated up to 90% penetration under certain testing conditions.

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PREFACE

The work described in this report was authorized under Project No. 56010632AA for the Department of the Army through the U.S. Army Corps of Engineers, U.S. Army Construction Engineering Laboratories Threatened and Endangered Species Program. This work was started in September 1995 and completed in January 1997.

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METHODOLOGY FOR MEASUREMENT OF FOG OIL SMOKE PENETRATION INTO A RED-COCKADED WOODPECKER NEST CAVITY

1. INTRODUCTION

For years the U.S. Army has been using battlefield smokes at training and development facilities throughout the United States and in other countries. Renewed awareness of the possible impact smoke usage may have on the environment and enactment of new clean air legislation nationwide has begun to limit open air smoke testing and training at numerous Army and Department of Defense locations. Of specific interest in the Southeast United States has been the protection of the avian species "Red-Cockaded Woodpecker" (RCW) listed as an endangered species within the Threatened and Endangered (T&E) listing. On installations known to have active RCW colonies the areas where smoke testing or troop training exercises occur is often modified or relocated to ensure that the RCW colony sites are protected. Smoke plume modeling and measurement studies, and environmental fate and effects investigations have been done to assess the impact of many smoke materials on the environment. However data did not exist to support or refute the possible protection from aerosols that a tree trunk nest cavity may afford its inhabitant. This is a first study to assess the potential for RCW exposure to smoke/obscurants within the nest cavity where the youngest and most susceptible of the species reside.

The home range of the RCW (*Picoides borealis*) is located in the old growth pine forests of the southeastern United States. Most of the active RCW colony sites now reside on state and federally owned forests, parks and military reservations. Army installations known to have historical or active RCW colonies are listed in Table 1.

TABLE 1. U.S. Army installations known to have active or historical RCW colonies.

Installation	State	Population Status
Fort Benning	Georgia	RCWs present
Fort Bragg	North Carolina	RCWs present
Fort Gordon	Georgia	Historical population
Fort Jackson	South Carolina	RCWs present
Fort McClellan	Alabama	Historical population
Fort Polk	Louisiana	RCWs present
Fort Stewart	Georgia	RCWs present
Louisiana Army Ammunition Plant (LAAP)	Louisiana	Historical population
Military Ocean Terminal, Sunny Point (MOTSU)	North Carolina	RCWs present

The Department of the Army (DA) working through the Army Corps of Engineers in cooperation with the U.S. Fish and Wildlife Service has drafted new guidelines for management of RCW's.[1] This program includes assessment of the potential impact smoke producing operations may have on individual RCW's and RCW colony sites. The U.S. Army Corps of

Engineers, Construction Engineering Research Laboratories has sponsored this work to determine if Fog Oil (FO) smoke does penetrate into the tree trunk nest cavity of the RCW.

2. METHODOLOGY

The work in this report describes two related studies to assess the potential for FO penetration into RCW nest cavities. The first study started in September 1995 was conducted at the US Army Edgewood Chemical Biological Center (ECBC),* Aberdeen Proving Ground, MD. The study at ECBC utilized a model RCW nest cavity. The second study was conducted at the Pacific Northwest Laboratories (PNL), Richland, Washington in November 1996. This study was a follow-on to the work conducted at ERDEC. The study there utilized an actual abandoned RCW nest cavity harvested after the tree had been blown down in a storm.

The test methodology consists of challenging the nest cavity with a thermally generated FO cloud under active wind conditions, and measuring the challenge FO cloud concentration and the concentration of any FO that penetrates into the nest cavity.

2.1 Study 1; Testing at ECBC

This initial study was intended to gather first time information on possible FO penetration into a tree trunk nest cavity. The results of this study would be used for identifying the need for any additional work on the topic. The short lead time and nature of the funding required a quick startup and timely reporting of findings. In light of limited access to actual RCW nest cavities and planned milestones for this project, a model RCW nest cavity was manufactured in accordance with the methods of Taylor and Hooper.[2] The use of a model nest cavity was determined to be valid since the methods to make this model was used extensively in the field in the Francis Marion National Forest, and other locations, after hurricane Hugo destroyed 87 percent of the RCW nest cavities there in 1989.[3] Additionally RCW colonies have occupied the nest cavities made using this technique.

2.1.1 Model Nest Cavity Construction

The model nest cavity was made per Taylor and Hooper, by drilling into a harvested scrub pine that had been previously blow down. While this is not the recommended tree species for supporting an actual RCW nest cavity, the required dimensions of the tree trunk and dimensions of the cavity and entrance were strictly followed. Two additional holes were made near the bottom of the cavity, at an approximate head height of an RCW on a nest, to allow controlled removal and return of sample of air from inside the nest cavity.

*Formerly U.S. Army Edgewood Research, Development and Engineering Center (ERDEC).

2.1.2 FO Generation

The challenge FO aerosol was generated using a prototype, bench scale, small engine exhaust system (SEES). The SEES consisted of a modified gasoline powered portable electric generator with the muffler replaced by a piece of 1 1/2 in. steel pipe with a liquid injection port. A 1 kw heat strip was wrapped around the steel exhaust pipe to provide the additional heat required for vaporization of the FO. The electric generator provided enough power to operate the heat tape and power a pump to transfer the FO from a reservoir into the FO injector. Exhaust from the 7 hp gas engine acted as a carrier gas and was used to help heat the exhaust pipe and vaporize the FO. The SEES has an FO dissemination capacity of 2 gal/hr.

2.1.3 FO Measurement

The FO smoke concentrations were measured using Real-time Aerosol Sensors (RAS) supplied through MIE Inc.[4] An RAS is a light scattering instruments used in many field applications for measuring smoke concentrations in the range of 0.01 to 1000 mg/m^3 for particles 0.1 to 10 μm in diameter. The RAS uses a broad spectrum light source to illuminate smoke particles in the light stream, a detector senses the intensity of the illuminated particles. The RAS reports the illumination as an analog mv output proportional to the smoke concentration. The challenge FO smoke concentration was measured using an open flow-through sensing chamber. The sample of the air from within the nest cavity was removed at a flow rate of 60 cc/min through a RAS with an optional closed ended sensing chamber and then returned untreated to the nest cavity to ensure proper air balance. The analog output from each RAS was recorded real-time on a DASH 8 data logger. The RAS output in millivolts was later converted to FO concentrations using a linear regression equation from gravimetric calibrations using FO aerosols. Both challenge and penetration FO concentrations were required to be stable within 5% for 1-min intervals before a data point was considered valid. Mean concentration for that 1-min interval was then used as a single data point. The concentrations were reported as milligrams per meter cubed (mg/M^3) for challenge and penetration concentrations. Smoke penetration was also reported as percent of challenge concentration of FO penetrating the nest cavity.

Fog Oil smoke particle size was measured using an eight stage Anderson Cascade Impactor. The impactor had a size measurement range of 0.0 to 9.0 μm.

2.1.4 Test Setup

The challenge aerosol was generated into an open ended breeze tunnel 8 ft height, 10 ft wide in a half round configuration, 140 ft long. Electric fans were used to generate air flow through the tunnel. The fans were directed diagonally to the direction of flow to ensure mixing and to create a turbulent flow that may be more representative of a natural setting. The model nest cavity and aerosol sensing equipment were placed inside the breeze tunnel 75 ft from the FO generator. A rubber stopper was used to plug the cavity entrance. An initial null test was conducted to ensure that there was no FO penetration into the cavity or the FO measuring system

other than through the nest cavity entrance. Measurements of FO penetration into the nest cavity were taken at two orientations, the first with the nest entrance facing into the wind, the second with the nest entrance facing perpendicular (90° opposed) to the wind. The FO was generated at three concentrations per nest cavity orientations.

2.2 Study 2; Testing at PNL

2.2.1 The Nest Cavity

The FO penetration testing at PNL was done using a natural, RCW constructed, tree trunk nest cavity that had been blown down and subsequently abandoned by the birds. The nest cavity used was one of three that were available. The nest that was selected was considered to most closely resemble a typical RCW nest cavity and the model nest cavity previously used at ERDEC.

2.2.2 FO Generation

The FO smoke was generated thermally using an electrical immersion heater. Nitrogen was passed through a metal pipe containing two heat zones. Zone 1 was heated to 600°C using a 1 KW immersion heater. Zone two was maintained at 300°C using electric heat tape. Liquid FO was pumped from a reservoir into the heated pipe near the end of zone 1. The FO was vaporized as it passed along the pipe through the two heated zones. The vaporized FO was the condensed as it merged with cooler dilution air in an aging chamber before being released into a closed loop wind tunnel.[5] This heater is represented in Figure 1 below.

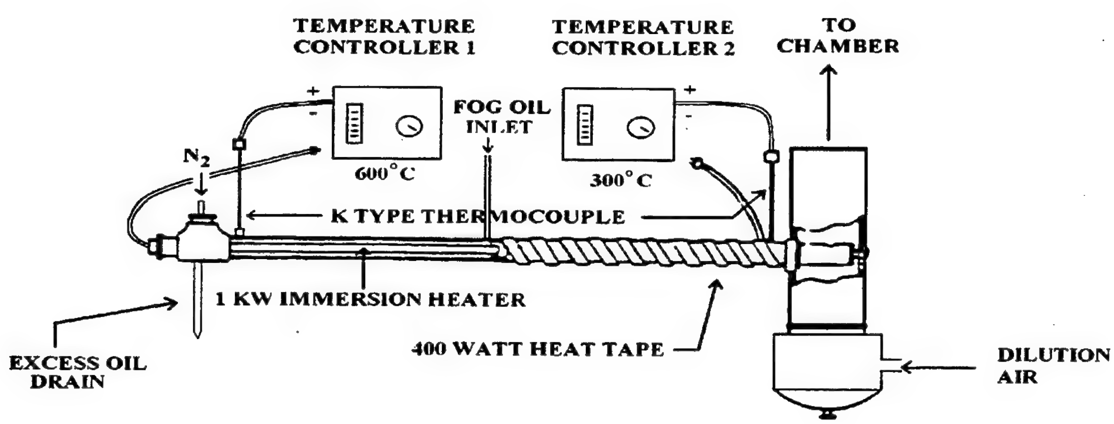

Figure 1. Schematic of Test Facility FO Generator.

2.2.3 FO Measurement

The FO concentration was measured with the same RAS's as used at ERDEC. The RAS's were carried to the PNL site and calibrated gravimetrically using FO generated there prior to testing. An FO sample loop was made with one of the nest cavities in the same fashion as the testing at ERDEC. Particle size of FO aerosol was measured using an Anderson cascade impactor.

2.2.4 Test Setup

The PNL maintains a fully enclosed recirculating wind tunnel at their aerosol research facility. This facility, represented in Figure 2 below, is more completely described by Cataldo et al.[5] The RCW nest cavity was exposed to FO aerosol in the tunnel test section (Figure 3). The RAS sensors were used to measure the FO challenge concentration and the FO penetrating into the nest cavity. Prior to test initiation a rubber balloon was inflated in the entrance to the cavity as a stopper to ensure that there was no leakage of FO into the cavity other than through the cavity entrance. After a baseline showing no FO penetration the balloon was deflated and removed from the cavity. The FO exposure and penetration were made at 3 orientations, 0, 90, and 180°, relative to wind direction.

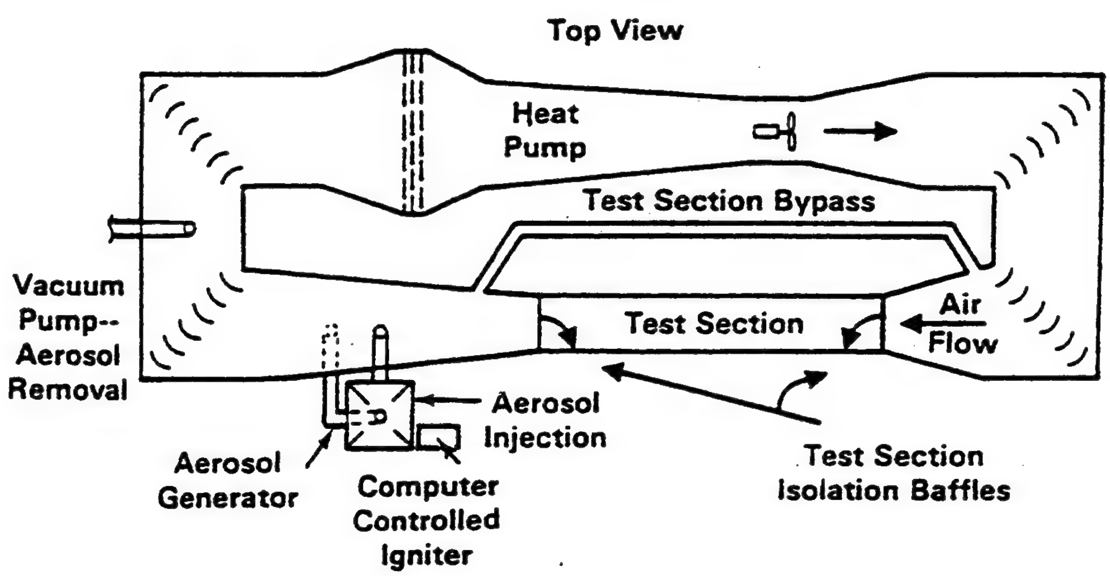

Figure 2. Schematic of the Closed Loop Wind Tunnel used for FO Penetration Testing.

3. RESULTS

3.1 Results from Testing at ECBC

The RAS output for real-time FO smoke concentrations inside and outside the model nest cavity were recorded on a strip chart data logger. The millivolt outputs were converted to FO concentrations in mg/M.^{3} Challenge and penetration concentrations are listed in Tables 2 and 3 below.

TABLE 2. FO Challenge and Penetration Concentrations, and Percent Penetration of FO into the Nest Cavity with the Nest Entrance Facing Into the Wind.

Challenge Concentration	Cavity Concentration	Percent Penetration
mg/M^3	mg/M^3	%
238.71	223.74	93.72
237.78	222.24	93.46
224.85	210.43	93.58
74.80	63.66	84.66
72.92	60.32	82.72
74.80	64.11	85.71
71.53	63.66	88.93
69.66	61.93	88.90
76.66	61.84	80.66
78.53	65.93	83.95
149.52	120.46	80.56
147.65	119.55	80.97
156.05	119.55	76.61

TABLE 3. FO Challenge and Penetration Concentrations, and Percent Penetration of FO into the Nest Cavity with the Nest Entrance Facing Perpendicular to the Wind Direction.

Challenge Concentration	**Cavity Concentration**	**Percent Penetration**
mg/M^3	**mg/M^3**	**%**
14.09	9.13	64.84
13.62	9.13	67.03
14.09	9.13	64.84
14.09	9.13	64.84
13.62	9.13	67.03
12.22	9.13	74.72
11.75	9.13	77.69
11.28	9.13	80.90
11.25	6.86	60.79
46.31	30.03	64.84
40.71	31.85	78.14
36.50	31.85	78.24
109.82	93.19	84.86
110.29	91.38	82.85

Air velocity of 3.1-4.1 mi/hr, was measured at the model nest cavity using a hot wire anemometer. Ambient temperature at the start of testing was 16.8°C. Aerodynamic mass median diameter of the FO aerosol was measured at 0.95 μm with standard deviation of 1.45. Thirteen data points were taken with the cavity opening facing into the wind. Fourteen data points were taken with the cavity perpendicular to the wind.

The three challenge concentrations measured during test 1, entrance into the wind (0°), were 233.78, 63.17, and 151.07 mg/M^3, respectively. Average percent penetration for the first orientation was 85.73%.

The three challenge concentrations measured during test 2, entrance perpendicular (90°) to wind direction were 12.89, 41.17, and 110.05 mg/M^3, respectively. Average percent penetration for the 90° orientation was 72.26%.

Descriptive Statistics

Variable	N	Mean	Median	Tr Mean	StDev	SE Mean
Penetration 90	14	72.26	70.88	72.16	8.12	2.17
Penetration 0	13	85.73	84.66	85.83	5.61	1.55

Variable	Min	Max	Q1	Q3
Penetration 90	60.79	84.86	64.84	78.91
Penetration 0	76.61	93.72	80.81	91.20

The student-t test for penetration vs orientation indicate no significant effect at p=.05. Data appear to indicate a possible challenge concentration effect on penetration, insufficient data points were available for penetration vs concentration analysis. The lack of more numerous data is due in part to the turbulent nature of the challenge airstream and our self imposed requirement of less than 5% variation in concentration for 1-min intervals for each penetration data point.

Two sample T-test for Penetration 90 vs Penetration 0

	N	Mean	StDev	SE Mean
Penetrat 90	14	72.26	8.12	2.2
Penetrat 0	13	85.73	5.61	1.6

95% CI for mu Penetrat - mu Penetrat: (-19.0, -7.9)
T-Test mu Penetrat = mu Penetrat (vs not =): T= -5.04 P=0.0000 DF= 23

3.2 Results from Testing at PNL

The penetration testing conducted at PNL was done under more controlled conditions. This allowed collection of more data points for each orientation tested. Therefore, individual data points are not listed here. While there was greatly improved precision in controlling challenge concentration and wind speed, the decrease in total FO generation capability and system equilibration period precluded the collection of data at multiple challenge concentrations.

The meteorological conditions inside the tunnel test section were:

wind speed:	1M/sec
relative humidity (start):	61%
relative humidity (end):	57%
Temperature:	27 °C

Requirements for valid data points were the same as testing at APG, 5% or less variation for 1-min intervals. Twenty-eight data points were taken with the cavity entrance facing into the wind (0°). The average challenge concentration was measured at 166.17 mg/M^3. Fifty-six data points were taken with the cavity entrance 180° away from the wind. The average challenge concentration for 180° was 173.45 mg/M^3. Seventy-six data points were taken with the cavity entrance oriented 90° to the challenge air flow. The average concentration was measured at 172.80 mg/M^3.

Descriptive statistics for FO challenge concentrations.

Variable		N	Mean	Median	Tr Mean	StDev	SE Mean
Challenge1	0°	28	166.17	167.41	166.22	2.15	0.41
Challenge2	180°	56	173.45	174.35	173.58	1.33	0.18
Challenge3	90°	76	172.80	173.36	172.89	1.69	0.19

Variable		Min	Max	Q1	Q3
Challenge1	0°	162.45	168.40	163.69	167.41
Challenge2	180°	170.38	174.35	172.61	174.35
Challenge3	90°	169.39	174.35	171.37	174.35

Descriptive statistics for FO Penetration

Variable		N	Mean	Median	Tr Mean	StDev	SE Mean
% Penetration1	0°	28	88.332	87.485	88.346	2.520	0.476
% Penetration2	180°	56	91.830	92.090	91.869	1.293	0.173
% Penetration3	90°	76	94.485	94.884	94.593	1.449	0.166

Variable		Min	Max	Q1	Q3
% Penetration1	0°	84.145	92.152	86.113	91.485
% Penetration2	180°	89.122	94.034	90.920	92.964
% Penetration3	90°	89.887	96.165	93.496	95.525

One-Way Analysis of Variance

Analysis of Variance for % Penetration

Source	DF	SS	MS	F	P
Direction	2	811.00	405.50	151.24	0.000
Error	157	420.96	2.68		
Total	159	1231.96			

```
                                  Individual 95% CIs For Mean
                                  Based on Pooled StDev
Level   N    Mean     StDev      --+---------+---------+---------+----
  0    28   88.332    2.520       (--*--)
 90    56   91.830    1.293                         (-*-)
180    76   94.485    1.449                                     (*-)
                                 --+---------+---------+---------+----
Pooled StDev =  1.637              88.0      90.0      92.0      94.0
```

Tukey's pairwise comparisons

Family error rate = 0.0500
Individual error rate = 0.0192

Critical value = 3.35

Intervals for (column level mean) - (row level mean)

	0	90
90	-4.396 -2.601	
180	-7.011 -5.296	-3.338 -1.972

4. CONCLUSIONS

Data show that Fog Oil (FO) aerosol does penetrate into the RCW model nest cavity under the test conditions described. There may be an effect of lessening the level of smoke penetration with changes in the orientation of the nest cavity entrance. The average concentration of smoke entering the cavity was 85.7 ± 5.6% of the challenge concentration when the nest opening faced directly into the wind. The average concentration with the nest opening perpendicular to the wind was lower at 72.3 ± 8.1% of the challenge concentration.

The data show that FO smoke may penetrate into an RCW nest cavity under the test conditions used. The orientation of the nest opening has some bearing on the relative amount of the smoke that penetrates into the nest cavity. While this initial testing does give indications that FO smoke penetrates into the nest, this limited data cannot fully explain the magnitude of penetration and the effects of other variables that could contribute to nest cavity intrusion. This limited data should not be used by itself as proof that FO will be expected to penetrate into an actual RCW nest cavity during a given field smoking exercise, only that it may occur. It is highly recommended that further testing be conducted, and is planned that parameters include, but not be limited to, variations in wind speed, wind turbulence, nest entrance orientation and FO concentrations.

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